# NOAA
# Joint Pilot Project on Eelgrass (*Zostera marina* L.) Recovery in San Francisco Bay

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# INTRODUCTION

NOAA's National Ocean Service (NOS) Eelgrass Pilot Recovery Project, funded under the NOS Partnership Program in FY 02, was initiated in the Spring of 2003. Integrated with a larger study coordinated by NMFS, an eelgrass recovery and population ecology project was initiated at several sites within the Bay. The purpose of the recovery project was to provide recovery rate data for planning of restoration projects, which provides the basis for computation of interim lost resource services and restoration planning. The population ecology portion of the project expanded the investigation into previously identified annual and perennial growth forms of eelgrass over large areas of the Bay (Fredette et al. 1987). This fact is important since an unusually high prevalence of annuals would dramatically alter options for restoration and expectations for management as west coast restoration strategies have heretofore been based on perennial growth strategies (Fonseca et al. 1998). These studies, along with others (Merkel and Associates, Inc. 1999a,b, Wyllie Echeverria and Rutten 1989) are being undertaken because, after ~20 years of sporadic studies, many crucial questions remain unanswered in order to put forward a coherent management and restoration strategy for San Francisco Bay eelgrass. At this time, most questions revolve around aspects of population ecology and physical setting of eelgrass beds, as these data provide the template for what can be attempted and expected with restoration (see accompanying Literature Review, this volume).

The accompanying Literature Review suggested that the critical outstanding questions include (bold faced items indicate targets of the present study):

1. **What is the role of seeding vs. vegetative reproduction in bed maintenance?**
2. What are the major environmental stressors, when do they occur and how are these distributed across the Bay?
3. **What are the appropriate seasons for planting (i.e., planting time maximizes the time since the major annual stressor that limits eelgrass growth and colonization)?**
4. **At what rate do vegetative plantings expand?**
5. **At what rate do injuries re-colonize?**
6. **What is the appropriate transplanting technique(s)? Should emphasis continue on whole plant transplanting or should seeding techniques be evaluated?**
7. What is the role of biological disturbance, if any, in limiting restoration efforts (this has proven to be a consistent bottleneck for seagrass restoration worldwide)?
8. Where are the suitable restoration sites?
9. Can a monitoring network be established that produces a forecasting tool for setting water quality improvement targets, identification of water quality deterioration sources, and delineation of potential restoration sites?
10. What is the use of the remaining Bay area eelgrass beds by economically valuable species?

This preliminary study then focuses on Items 1, 3, 4, 5 and 6, above (bold typeface). Item 1, "**What is the role of seeding vs. vegetative reproduction in bed maintenance?"** was addressed through assessment of reproductive effort by the plants at several sites around the Bay and is part of the population ecology portion of the study. Similarly, Item 3, "**What are the appropriate seasons for planting (i.e., planting time maximizes the time since the major annual stressor that limits eelgrass growth and colonization)?"** was assessed by detailed, morphometric examination of eelgrass rhizomes, which provide a growth history of the plants. Item 4: "**At what rate do vegetative plantings expand?"** will addressed both through rhizome mapping, tracking of clonal units, and closure of excavation plots. Item 5, **"At what rate do injuries re-colonize?"** was addressed through the creation of injury recovery plots within existing beds and assessment of their recolonization over time. Item 6, "**What is the appropriate transplanting technique(s)? Should emphasis continue on whole plant transplanting or should seeding techniques be evaluated?"** will be resolved through evaluation of flowering intensity and seedling colonization work. Work planned for FY04 builds upon these preliminary assessments and is described below.

# METHODS

**San Francisco Bay**:_Work was initiated in April 2003 to coincide with astronomical low tides and the spring growth characteristic of eelgrass in the Bay area. The locations of our study sites are given in Figure 1. Although the Keil Cove site is listed as a study area, access has subsequently been denied by the property holders and the matter is being investigated by NMFS. Therefore, only partial information is provided at this site and it is not included in our data analysis. See photo plates at end of the document for site views.

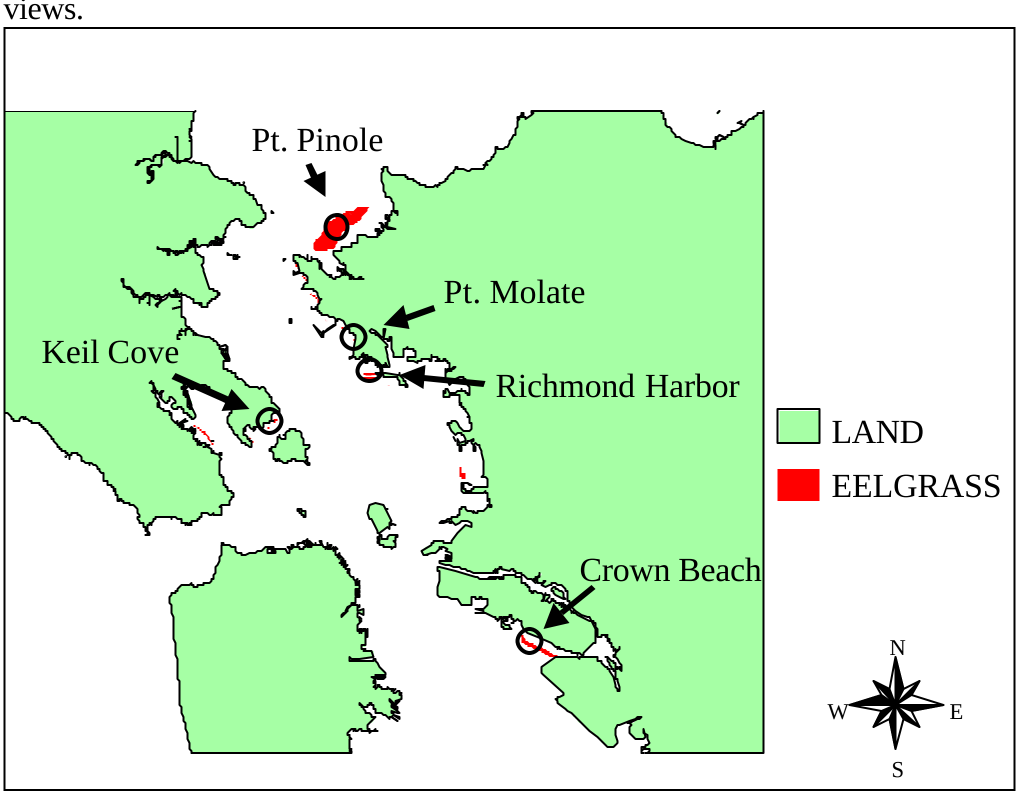

**Figure 1. Study site locations for 2003.**

Clearance plots: This experiment was initiated to provide data with which to compute the intrinsic recovery rates of eelgrass, which is a critical input parameter for computation of lost interim resource services, using Habitat Equivalency Analysis (HEA) – a mainstay of NOAA's response to Natural Resource Damage Assessment nationwide (Fonseca et al. 2000). At Pt. Pinole and Keil Cove we cleared three 1 $m^2$ plots, while at Pt. Molate, where plant densities were noticeably higher, four, 0.25 $m^2$ plots were cleared (Table 1). In each of these plots, we collected the following information in April (time 0), June and August, 2003:

1. Voucher specimens (April only)
2. Shoot counts by vegetative state
3. Oblique photos
4. Trimble coordinates (sub-meter accuracy)
5. Associated arbitrary tosses (1 for every clearance plot)
    a. Shoot counts by vegetative state
    b. Oblique photos

The voucher specimens provide historical evidence of the status of the plants and are valuable for comparative analysis with other voucher samples, such as those placed at the University of California by Setchell in the early 20th Century (1929). Changes in the morphological characteristics of these plants over time may provide clues to the stresses imposed on the Bay (e.g., finding longer plants now as opposed to 80 years ago may signal reduction in light availability) and may be useful in genetic analyses.

Shoot counts of both vegetative shoots and those that have begun to metamorphose into flowering shoots, over time, are used to gauge the recolonization rate of injured areas, the algorithm of which is used in HEA to compute interim lost resource services. The differentiation among vegetative and flowering shoots is important for several reasons. First, one expects ~13% of the population to be flowering in a typical eelgrass bed in North America. With this flowering level, whole-plant transplantation is feasible as most of the stock is vegetative – meaning that it will spread and branch across the bottom for another 1-2 years before new and extant shoots flower and die. However, we have recorded very high flowering levels in the Bay (Fredette et al. 1987; this study), which decreases the effectiveness of these traditional planting techniques that rely on vegetative shoots. Therefore, a census of flowering is a critical first step to determining the potential impact on restoration strategies, as well as building a forecasting tool to predict flowering level (see section below on FY 04 continued work). Percent cover of the bottom is performed using the Braun-Blanquet method (Fonseca et al. 1998) in an attempt to develop a visual census tool for these very large plants, which could be significantly less expensive than direct shoot counts.

With the computation of recovery rates, we are poised to conduct a comparative HEA with other seagrasses in the United States so as to gauge the consequences of eelgrass loss in the context of resource service flows. Because these techniques have been applied to other seagrass ecosystems in the U.S. and defended successfully in Federal Court, a comparative analysis will provide us with a greater understanding of the restoration costs associated with injuries to this resource.

Table 1. San Francisco Bay Project Location of Experimental Plots. Plots established 7-11 April 2003. Names and positions of permanent sample plots.

| **Site and Replicate Plot** | **Longitude** | **Latitude** |
|---|---|---|
| CROWN BEACH – population ecology | | |
| Crown 1 | -122.268750537 | 37.758986685 |
| Crown 2 | -122.268786992 | 37.758996396 |
| Crown 3 | -122.268903076 | 37.759007956 |
| Crown 4 | -122.268984086 | 37.759030354 |
| Crown 5 | -122.269046317 | 37.759069086 |
| Crown 6 | -122.269116275 | 37.759056229 |
| Crown 7 | -122.269191452 | 37.759075113 |
| Crown 8 | -122.269244291 | 37.759074869 |
| Crown 9 | Missing | Missing |
| Crown 10 | -122.269671339 | 37.759193717 |
| KIEL COVE – clearance plots | | |
| Kiel Cove A | -122.441983238 | 37.880576964 |
| Kiel Cove B | -122.442519105 | 37.880303563 |
| Kiel Cove C | -122.442632707 | 37.880223748 |
| POINT MOLATE – clearance plots | | |
| Pt. Molate 2 | -122.412549842 | 37.941377220 |
| Pt. Molate 3 | -122.412497090 | 37.941474738 |
| Pt. Molate 4 | -122.412453170 | 37.941600597 |
| Pt. Molate 5 | -122.412558360 | 37.941779929 |
| PT PINOLE – clearance plots | | |
| Pt. Pinole 1 | -122.420936341 | 37.972677576 |
| Pt. Pinole 2 | -122.420685551 | 37.972811521 |
| Pt. Pinole 3 | -122.420521084 | 37.972932852 |
| PORT RICHMOND INNER HARBOR – Fredette et al. 1987 study area | | |
| Richmond 1 | -122.381473685 | 37.903262266 |
| Richmond 2 | -122.381364305 | 37.903086339 |
| Richmond 3 | -122.380628376 | 37.903074903 |

Population Ecology: This sampling was closely tied to clearance plot work, and indeed, utilizes some of the same data (see locations, Table 1). However, data collection described in this section goes into greater detail of the plant ecology, which is required for determining a cause of the variable reproductive strategies, as opposed to just a prediction of recovery and restoration alternatives. With a focus on cause, we are beginning our attempt to develop a forecasting tool in FY04 (see below) that would provide a parsimonious guide to assessing impacts and devising mitigative strategies.

At sites with clearance plots (Pts. Molate and Pinole, Keil Cove) we conducted arbitrary tosses of sample quadrats the same size as used in the clearance plots onto the undisturbed eelgrass adjacent to the recovery plots, but no closer than ~five meters away. Again, shoots counts were made for each vegetative state, for comparison not only with the recovery plots so as to determine when recovery was indeed complete, but to evaluate the reproductive status of the beds independent of any potential alteration in strategy that might arise from the influence of the clearing process. Again, with these data, we contribute to the development of a forecasting tool. Oblique photographs were taken with a 4.0 megapixel digital still camera and an estimate of cover using the Braun-Blanquet technique was made from the photograph.

We mapped seagrass cover by conducting walking video transects (except in one case where the video was necessarily shot from the boat) using a Sony 900 digital video camera at ~ 1m above either the water surface, or, when the site was emersed, above the sediment. The video was shot with the camera facing down, as close to the vertical as could be manually achieved. A Trimble ProXRS differential global positioning system was carried with the camera, providing a simultaneous record of seagrass cover, vegetative status, and sub-meter accurate position. The position file was downloaded to Excel and amended with a record of seagrass cover (yes/no; any evidence of eelgrass within the frame constituted a "yes"), number of flowering shoots, and when the sediment was visible (typically, emersed sites), a yes/no record of biological disturbance pits (*sensu* Townsend and Fonseca 1998). The transect pattern consisted of 2-3 lines running from the deep edge of the distribution to the shallowest edge (as determined by eye), and 2-3 lines running along a constant elevation; most transects were > 100m. These data provide us with crucial large-scale information about flowering effort across the plant's elevation range that will aid in the quantification of suitable vertical range for restoration as well as the effect of setting on colonization pattern (a combination of recruitment effectiveness and subsequent growth strategy). We will present the georectified assessment of the aforementioned factors here and make them available upon request in a common industry format (ESRI).

At each site, plants were excavated with intact rhizome systems. When possible, entire genets were removed and kept physically intact. This sample collection allowed us to map the rhizome structure which in turn yields a recent history of the growth strategy of the plants. The number of root nodes (which are laid down coincident with emergence of a new leaf, the timing of which is generally known from the literature, providing us with a ability to determine how much time it took to produce the various branches, shoots, flowers, etc., and whether flowering occurred in the first year of growth since germination from seed – a definition of an annual for eelgrass – as all this can be deduced through a visual inspection and morphometric recording of the rhizome matrix) were counted and measured to the nearest 0.01mm - the length of the nodes which yields another measure of plant colonization rate, and seasonality of productivity. Longest blade length and width were recorded to aid in relating plant morphology to growth strategy which in turn provides important clues for restoration strategy (spacing of planted shoots a given site). Collection intensity was variable, depending on the time of year. Time 0 (April) was limited because newly germinated shoots had not yet begun to spread in earnest and thus it was premature to collect whole genets for rhizome analysis. Similarly, June collects were considered redundant as the August sampling would capture the entire growth history from before April.


**Figure 2. Close-up of rhizome internode recording.**

At Crown Beach, we adapted a different sampling strategy in response to a significant seedling colonization event that was occurring in the spring of 2003. Here, the broad (> 300m) shallow shelving structure of Crown Beach was experiencing a high level of eelgrass seedling colonization. Video transects were recorded in June and August as at other sites. However, starting in April 2003, ten 1 $m^2$ permanent plots were staked out for monitoring at approximately halfway up the elevation gradient of the local eelgrass population (from deep to shallow). Two plots were lost, and eight are being monitored for seedling number, genet size by seedling, and flowering frequency – all by direct counts. Each plot was photographed each survey time and Trimble DGPS coordinated taken for each plot. Voucher specimens were made in April of the seedlings with attached seeds.

In June and August, whole genets (clonal units) for rhizome mappings and pressing were collected to compare development rates of the plants through morphometric analysis of plant size and rhizome structure as done at other sites (Figure 3). In August 2003 we installed two temperature loggers even with the surface of the sediment; one at the mid-point of the distribution (near the permanent plots) and ~ halfway from that point to the shallow edge. Loggers were started on August 30th and sample ambient temperature every 15 minutes. We are collecting these data as sediment temperature is suspected as strongly influencing seed germination (author's unpublished data).

**Figure 3. Genet or clonal unit being collected at Crown Beach in August. Note the coarser sediment in the patch, indicative of the higher bed turbulence generated by the eelgrass patch.**

Fredette et al. (1987) conducted eelgrass planting experiments in Richmond Harbor. We revisited this site in June 2003 and we collected three clonal units in June 2003. These were returned from the field for rhizome mapping as described above.

In addition, NMFS and University of Alaska researchers visited most of these sites in July 2003 and obtained tissue samples for genetic analysis. We are awaiting results of those tests and will attempt to integrate those results with the present field studies. The outstanding questions that may be resolved by this comparison are:

1. Is the expression of annuality in the population based on selected survival of locally adapted gene complexes in areas with environmental conditions that favor the annual strategy, or
2. Is the genotype of the plants well mixed and the emergence of annuality a response that is driven by local environmental conditions? In other words, does eelgrass has a reproductive plasticity manifested in as alteration of reproductive effort among sexual vs. asexual strategies that is cued by local environmental conditions?

**Puget Sound**: Although not part of this study, similar work is being conducted in the State of Washington at three sites, each with 2-3 clearance plots per site, in an attempt to begin a more regional assessment of how eelgrass recovers from injury. Sampling is identical to that described above, and is mentioned here for information purposes only and no data are yet available from this unsupported effort.

**Capitalizing on FY02-03 Work – Expansion into Forecasting Tool Development in FY04:** NCCOS has provided additional funding for FY04 entitled: “GIS-based eelgrass management and restoration protocols for San Francisco Bay”. This work focuses on the fact that while it is important to have identified the reproductive status of eelgrass for implementation of NOAA’s protocols regarding injury assessment, recovery, and determination of compensation, it would be extremely useful to forecast where and when this may occur. Because we expect that environmental stress is linked to expression of annuality, we would conduct surveys of the geographic location of the annuals and perennials using direct examination of plants, DGPS and side-scan sonar for quantifying association with landscape attributes. We would then use existing models (Koch et al. 1997) that relate water depth, turbidity and tidal amplitude as well as wave exposure (WEMOdel; CCFHR; Fonseca et al. 2002) to construct polytamous multiple logistic regressions that would to translate the mathematical construct back into a geographic context that predicts occurrence of this reproductive strategy. With this crucial management issue resolved, the final result would be a GIS product that would not only show the probability of occurrence, but would automatically link to the recommended restoration strategy for a given restoration site, drawing on our previous synthesis work and knowledge of seagrass restoration. Moreover, this analysis would provide guidance on what environmental factors may be driving this stress-related shift in growth strategy by eelgrass, thus targeting those factors for amelioration by managers. Sampling and products include:

1. Continue video transect information on seagrass status – expand sampling where needed.
2. Obtain detailed bathymetric info at high tides over these sites (corrected for tidal stage and datum) using portable bathy survey system from Beaufort.
3. Obtain NOAA datum, bathymetry, tidal amplitude, currents, etc. via contract with Coastal Survey Development Laboratory.
4. Obtain water clarity and salinity information if possible.
5. Run WEMO.
6. Collect sediment compaction/penetrometry to relate to seed germination numbers and seed-size variation.
7. Consider seed bank assessment; compare with video estimate of clone abundance to estimate number of seeds needed to be sown to create a bed.
8. Create polytamous logistic multiple regression for distribution of flowering frequency as a function of water depth, tidal amplitude, light availability, sediment compaction, wave exposure and salinity.
9. Attempt to apply the a model of tide and light for predicting eelgrass distribution (Koch and Beer 1996).
10. Create GIS-based predictions of flowering and link with genetics surveys by projecting flowering frequency through the spatially registered independent variables found to account for significant variance under logistic regression and potentially, the Koch and Beer approach. Link results to recommended restoration strategies, costs and caveats.
11. Actively transfer products to clients.

# RESULTS TO DATE AND DISCUSSION

Voucher Specimens: These are retained by the University of Washington collaborators. These are undergoing rhizome analysis and no information is available at this date.

Clearance Plots - Shoot Counts by Vegetative State:
Figure 4 is a typical recovery plot showing pre-excavation conditions and three months

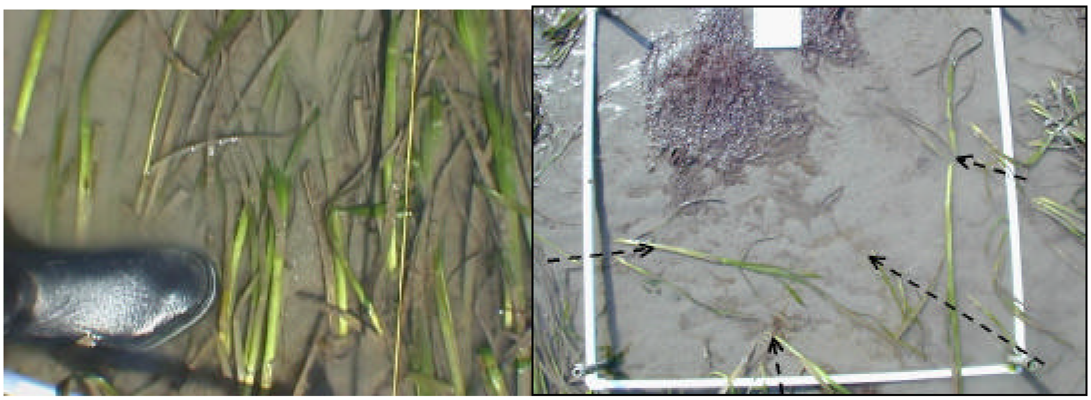

**Figure 4. Recovery into a plot at Pt. Pinole after ~four months. Left panel shows before (April) Arrows indicate location of new shoots that have migrated into the 1 x 1 m plot (June).**

after clearing. Figure 5 indicates the ambient density at Pt. Pinole over time as computed from the arbitrarily tossed quadrats onto adjacent, undisturbed eelgrass. Figure 6 is a plot of the recovery in these same plots at Pt. Pinole in June and August, 2003. Percent recovery of the excavated plots were:

| % recovery June | % recovery August |
| --- | --- |
| 61.5 | 64.3 |

Figure 7 indicates the ambient density at Pt. Molate over time as computed from the arbitrarily tossed quadrats onto adjacent, undisturbed eelgrass. Figure 8 is a plot of the recovery in these same plots at Pt. Pinole in June and August, 2003. Percent recovery of the excavated plots were:

| % recovery June | % recovery August |
| --- | --- |
| 27.3 | 81.8 |

Although significant recovery as a percent of the total ambient shoot density was rapid when compared with other seagrasses (Fonseca et al. in press), part of the rapid gain may be explained by a substantial drop in the ambient density over this time at both sites. Nonetheless, using percent shoot density recovered remains a valid metric in that these gains in shoot density in the excavated plots were attained in the face of dramatic seasonal declines in ambient shoot density.

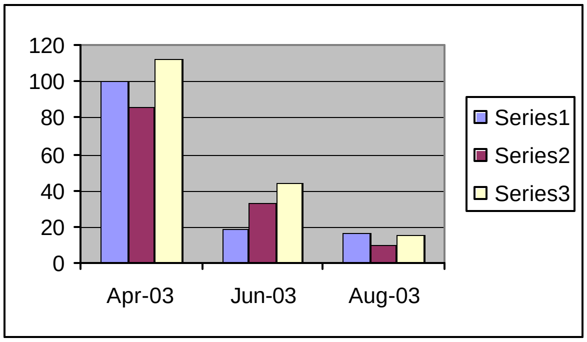


**Figure 5. Pt. Pinole ambient eelgrass shoot density per square meter. Series are replicate plots.**

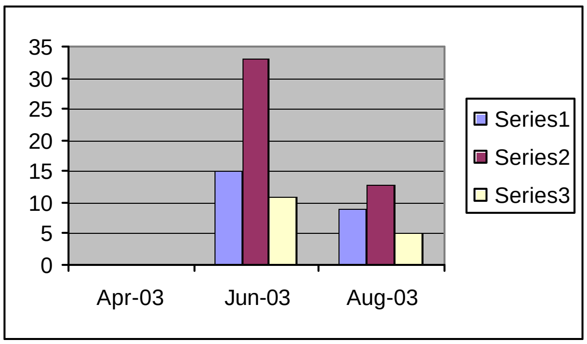


**Figure 6. Pt. Pinole recovery of excavated plots as shoots per square meter. Time 0 (excavation) occurred in April. Series are replicate plots.**

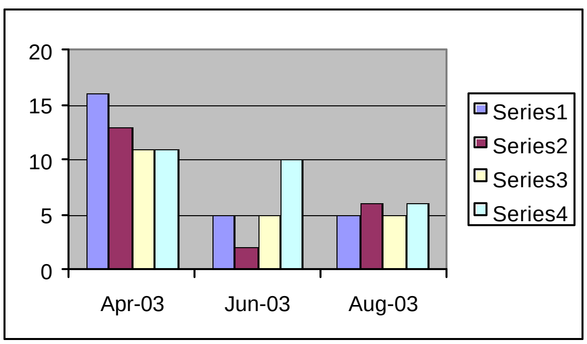


**Figure 7. Pt. Molate ambient eelgrass shoot density per 0.25 square meter. Series are replicate plots.**

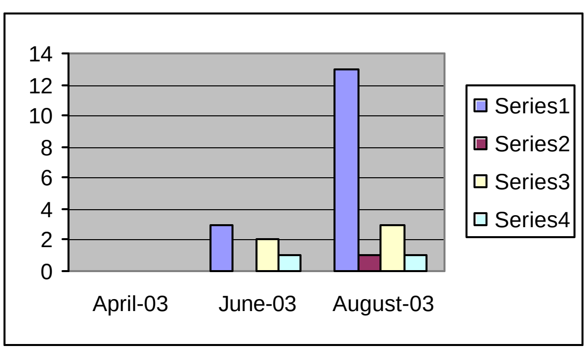


**Figure 8. Pt. Molate recovery of excavated plots as shoots per 0.25 square meter. Time 0 (excavation) occurred in April. Series are replicate plots.**

Photodocumentation: Copies of the video transects and oblique clearance plot photographs are maintained at the CCFHR. Copies are available upon request.

Population Ecology: Ambient densities at Pt. Pinole and Pt. Molate are given above, in Figures 5 and 7, respectively. Flowering at these sites is given in Tables 2 and 3, below.

Table 2. Pt. Pinole flowering as shoots per 1.0 square meter.

| Series | Apr-03 | Jun-03 | Aug-03 | |
|---|---|---|---|---|
| 1 | 0.0 | 2.0 | 0.0 | |
| 2 | 0.0 | 2.0 | 1.0 | |
| 3 | 13.0 | 4.0 | 1.0 | |
| Means | 4.3 | 2.7 | 0.7 | Grand Mean = 2.6 |

Table 3. Pt. Molate flowering as shoots per 0.25 square meter.

| Series | Apr-03 | Jun-03 | Aug-03 | |
|---|---|---|---|---|
| 1 | 0.0 | n/a | n/a | |
| 2 | 0.0 | 0.0 | 0.0 | |
| 3 | 0.0 | 0.0 | 1.0 | |
| 4 | 0.0 | 0.0 | 0.0 | |
| 5 | 0.0 | 3.0 | 1.0 | |
| Means | 0.0 | 0.8 | 0.5 | Grand Mean = 0.6 |

For Pt. Pinole, these values as a percent of the population that is flowering equals:

| % flowering June | % flowering August |
|---|---|
| 8.3 | 4.8 |

For Pt. Molate, these values are:

| % flowering June | % flowering August |
|---|---|
| 13.6 | 9.1 |

These levels of flowering are at the low end of the range of flowering typical of *Zostera marina* (Thayer et al. 1984) as compared to the east coast, but are not unusually low. Values from the east coast (New York to North Carolina) range between <10 and 27%. The drop in percent flowering from June to August at these sites also represents a not unexpected senescence of flowering stalks. Because these data are compiled separately from the vegetative shoot data used for computing percent recovery, the drop in flowering shoot numbers does not explain the drop in ambient shoot density over this time period. However, this drop from April to July was also observed by Fredette et al. 1987, suggesting that this is a typical seasonal phenomenon.

Walking Georeferenced Video at Clearance Plot Sites: Starting at Pt. Pinole, these data indicate a bed structure with very high, unbroken coverage. This is by far the largest known eelgrass bed in the watershed (Figure 1) and the high coverage and normal flowering abundance indicates a stable structure, and a good reference site for healthy eelgrass in this system (Figure 9). Pt. Molate coverage is much more patchy and is consistent with surveys at this site by Fredette et al. 1987 (Figure 10). We posit that this patchiness is indicative of a site where environmental conditions are less favorable than at Pt. Pinole and that patchiness here is a product of limited light availability and a shorter effective growing season . We speculate that Pt. Molate may be more exposed to waves, and being a fringing shoreline bed, does not have the geomorphological protection offered to eelgrass at Pt. Pinole where its existence on a large shoal should mitigate wave influence. Finally, we speculate that the Pt. Pinole site may enjoy some higher frequency clear water intrusions from the strong currents that pass around the Point, with direct connection to oceanic water; this would lead to somewhat clearer water on the average at this site. This remains to be tested, however.

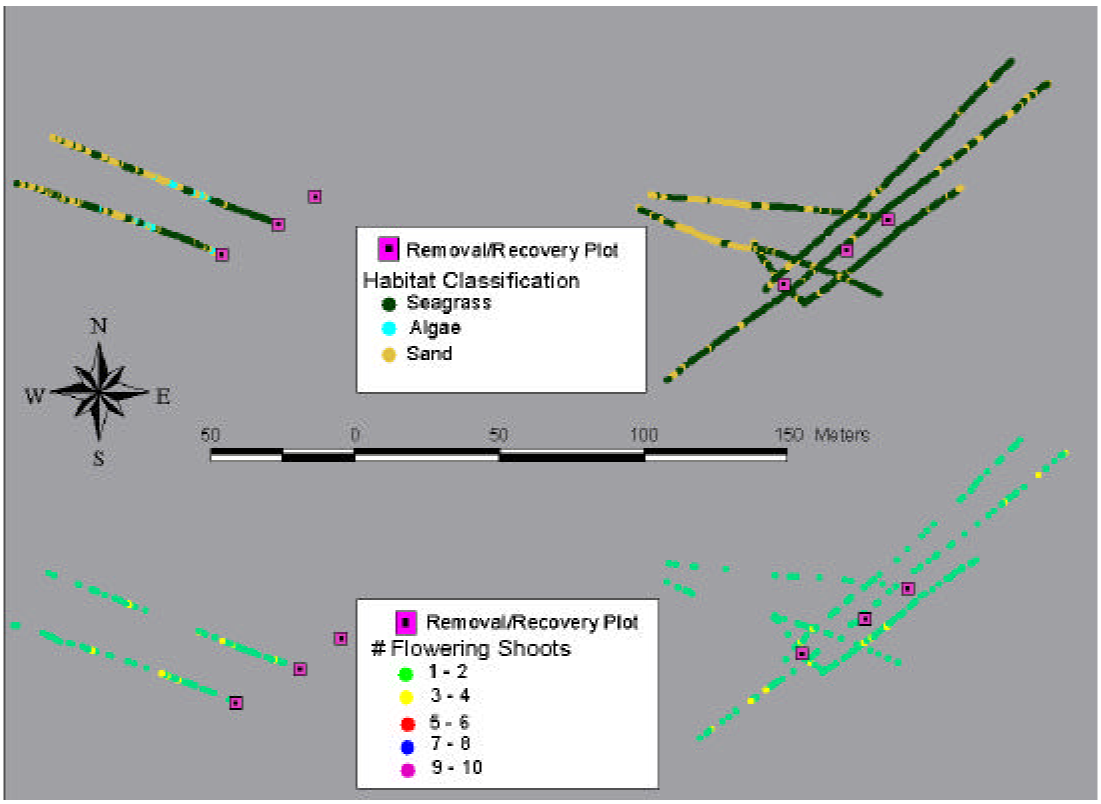


**Figure 9. Point Pinole videographic survey of seagrass, algae, sand and flowering. August 2003.**

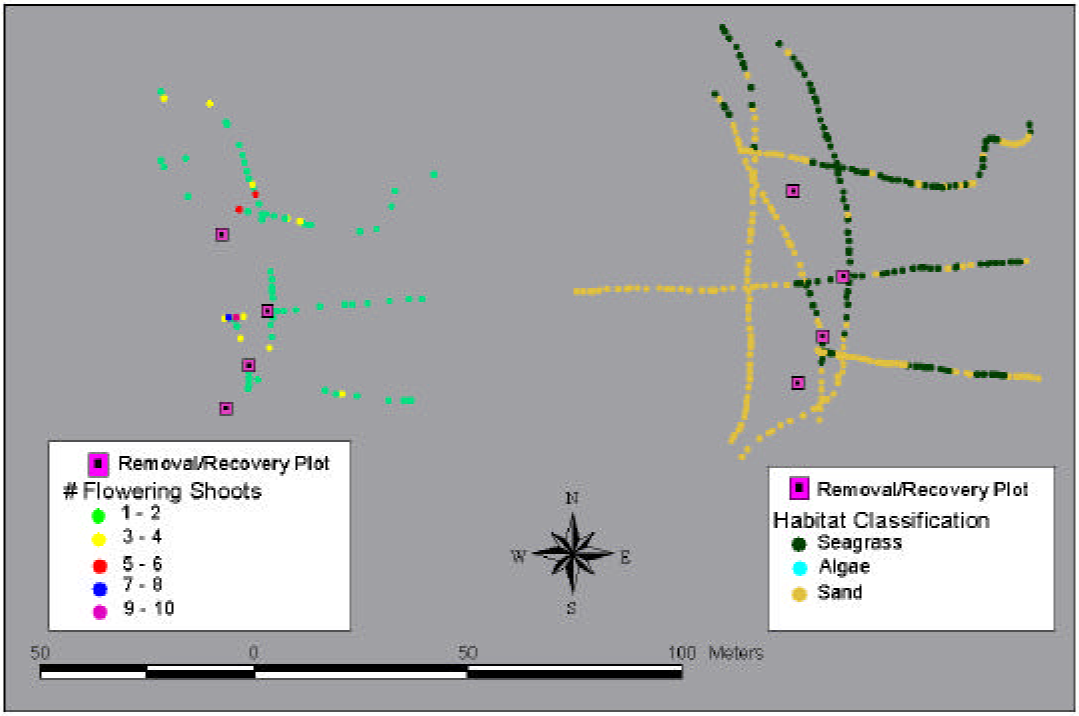


**Figure 10. Point Molate videographic survey of seagrass, algae, sand and flowering. August 2003.**

Rhizome Map Data: At this time, we have only recently (within the last month) completed measuring rhizomes and those data are under analysis. Besides an evaluation of seasonality and frequency of flowering, like Fredette et al. 1987, we will compute the time between branching events. This latter computation is an important indicator of appropriate planting season because planting just prior to the season when plants normally undergo frequent branching is an important restoration strategy to optimize anchoring and effective colonization. Moreover, rhizome mapping analysis may shed light on our speculations regarding why Pt. Molate is so much more patchy than Pt. Pinole.

Crown Beach Seedling Colonization Study: This study site is considered separately as there were no clearance plots established here. Rather, the permanent plots were established solely to track the development of newly germinated seedlings that were observed to have colonized this area in April. The rate of shoot density development is given in Figure 12, and the percent flowering in Table 4. Substantial increases in shoot numbers have occurred since April. Most interesting, however, is the prevalence of flowering shoots. Because these plots were placed around newly germinated seedlings

**Table 4. Vegetative shoots and flowering at Crown Beach.**

**Crown Beach vegetative shoots per square meter.**

| Series | Apr-03 | Jun-03 | Aug-03 |
|---|---|---|---|
| 1 | 10 | 18 | 19 |
| 2 | 4 | 5 | 1 |
| 3 | 3 | 8 | 8 |
| 4 | 1 | 1 | 1 |
| 5 | 7 | 6 | 5 |
| 6 | 8 | 0 | 0 |
| 7 | 5 | 11 | 9 |
| 8 | 7 | n/a | 13 |
| 9 | 6 | n/a | |
| 10 | 3 | 6 | 8 |
| Means | 5.4 | 6 | 8 |
| Grand Mean | | 6.5 | |

**Crown Beach flowering as shoots per square meter.**

| Series | Apr-03 | Jun-03 | Aug-03 |
|---|---|---|---|
| 1 | 0 | 3 | 12 |
| 2 | 0 | 1 | 4 |
| 3 | 0 | 1 | 6 |
| 4 | 0 | 1 | 0 |
| 5 | 0 | 1 | 4 |
| 6 | 0 | 0 | 0 |
| 7 | 0 | 1 | 2 |
| 8 | 0 | n/a | 0 |
| 9 | 0 | n/a | |
| 10 | 0 | 1 | 4 |
| Means | 0 | 1 | 4 |
| Grand Mean | | 1.67 | |

only four months prior to the August sampling, this high level of flowering provides strong proof of an annual component to this population:

| % flowering April | % flowering June | % flowering August |
|---|---|---|
| 0 | 17 | 50 |

The Walking Georeferenced Video at this site reveals a patchy colonization pattern and a extremely high frequency of flowering that again confirms the generally large annual component of this population (Figure 13). Over-wintering observations, the August installation of temperature loggers at this site, along with more detailed inundation computations to be conducted in 2004, and integration of ongoing genetic analysis by the University of Alaska will hopefully provide us with clues as to what is occurring at this site that results in such a high level of flowering as compared to Pt.

Pinole and Pt. Molate, where flowering is consistent with perennial populations elsewhere in the country.

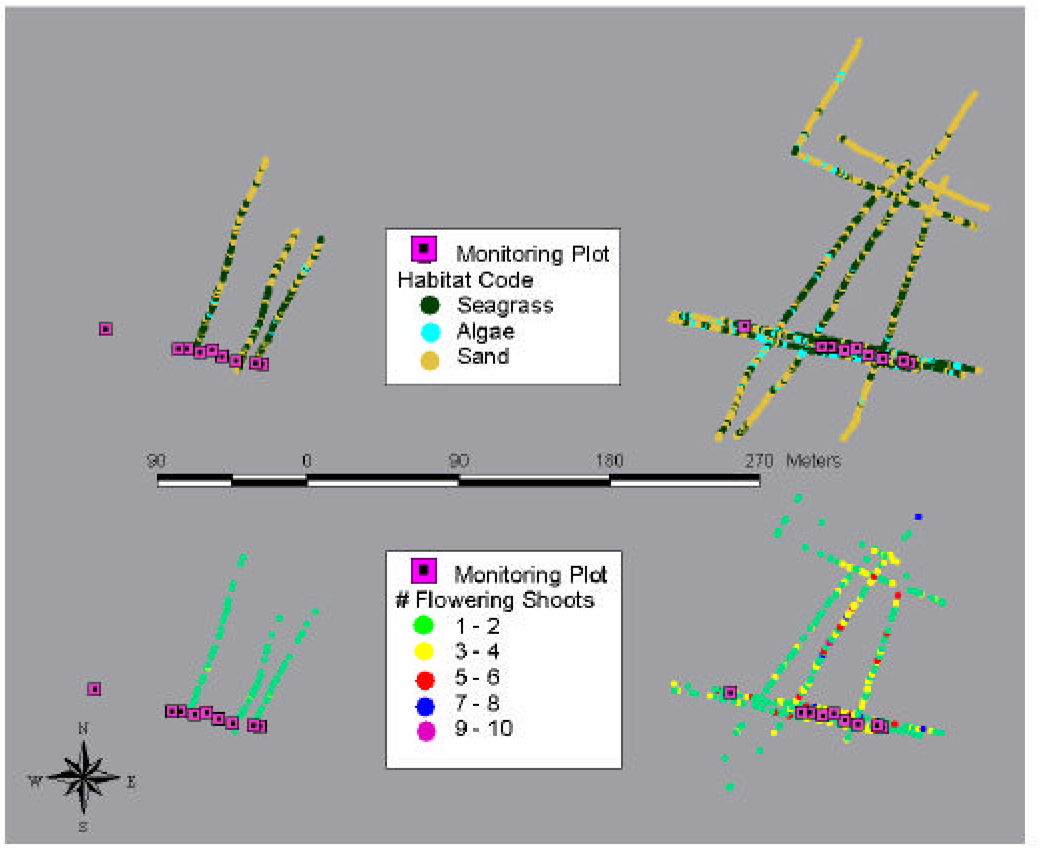


**Figure 13. Crown Beach videographic survey of seagrass, algae, sand and flowering. August 2003.**

<u>Point Richmond Observations</u>: In June 2003, we visited the Richmond Harbor site where Fredette et al. (1987) conducted their work. Three genets or clonal units were carefully extracted and returned for morphometric analysis. Although these data are pending, our observation at harvest was that each genet had risen from a seed earlier in the year (the seed coat was present on one unit). Moreover, it appeared that almost every shoot had flowered. Many shoots had senesced and the ends of the rhizomes were still crisp, but absent a short shoot. Those shoots that remained were almost all flowers. As indicated by Fredette et al. (1987), this site exhibits extremely high flowering and may be a fully annual bed. If so, this represents the extreme of flowering frequency of all sites observed in the Bay.

## CONCLUSIONS TO DATE

Our conclusions are in response to some of the questions poised earlier in the Introduction taken from the Literature Review. In particular, Items 1, 3, 4, 5, and 6 are relevant to this study.

First: **"What is the role of seeding vs. vegetative reproduction in bed maintenance?"** Although we have not completed our analysis, it seems that from both Fredette et al's (1987) and our observations in Richmond Harbor, the elevated level of flowering seen at some sites, and the extremely large scale recruitment and colonization at Crown Beach that seeding is a crucial part of the colonization and bed maintenance strategy for many areas in the Bay. Elsewhere, such as at Pt. Molate, Pt. Pinole and Keil Cove, normal levels of flowering occur and vegetative contributions to bed maintenance are very important for continued presence across seasons.

Second (third in the Introduction): **"What are the appropriate seasons for planting (i.e., planting time maximizes the time since the major annual stressor that limits eelgrass growth and colonization)?"** Answering this can be done more definitively when we have completed computation of the rhizome mapping. In general, the planting season appears to be typical for eelgrass as found elsewhere in the country – with spring plantings being appropriate. The efficacy of late summer seeding (mimicking natural recruitment) or sowing of seed in the spring nearer to the time of germination remains an outstanding question, however.

Third (fourth in the Introduction): **"At what rate do vegetative plantings expand?"** We did not perform plantings, therefore this was not directly tested in this study; the work being done by CALTRANS may address this more specifically. However, the rhizome mapping data will yield a null model of what natural beds are capable of in terms of a net expansion rate. Comparisons of planted bed performance vs. these data would provide a valuable restoration performance metric.

Fourth (fifth in the Introduction): **"At what rate do injuries re-colonize?"** We will continue monitoring these sites into 2004, hopefully until 100% recolonization occurs. In the interim, it appears that substantial vegetative recolonization at these small spatial scales can occur in five months (64.3 -81.8%). Whether this is sustained through the winter and into the spring and then on up to pre-injury conditions is worth evaluating. When full recovery is reached, we will place this recovery rate in the context needed to apply our typical Injury Recovery Model (Fonseca et al., In press), compare them with other recovery rates for other seagrasses, and translate this into restoration strategies based on our experience with sub-tropical species.

Fifth (or sixth in the Introduction): **"What is the appropriate transplanting technique(s)? Should emphasis continue on whole plant transplanting or should seeding techniques be evaluated?"** The great range of reproductive effort we have observed (apparently wholly annual to flowering at or slightly below the norm) argues for employment of traditional vegetative shoot transplantation as well as introduction of seeding technology. To our knowledge, seeding techniques have not been utilized in San Francisco Bay. The high level of annual expression and high levels of seed colonization (with its potential role in bed maintenance – the Crown Beach bed has been previously identified, yet virtually the entire area appeared to recolonize from seed this year) argues strongly for implementation of seeding methods.

All our conclusions should be significantly enhanced through the development of our forecasting tool that should give some quantification to where seeding would be needed for bed colonization and/or maintenance, as well why. Our early questions:

1. Is the expression of annuality in the population based on selected survival of locally adapted gene complexes in areas with environmental conditions that favor the annual strategy, or
2. Is the genotype of the plants well mixed and the emergence of annuality a response that is driven by local environmental conditions? In other words, does eelgrass has a reproductive plasticity manifested in as alteration of reproductive effort among sexual vs. asexual strategies that is cued by local environmental conditions,

await resolution that will emerge only with the full analysis of these data and its integration with successful genetic analysis of the populations. Our new study that builds on this one is intended to forecast flowering and thus, seedling efforts which in turn guides placement of restoration technology. Providing resource managers a mature restoration strategy in addition to an explanation and forecast of flowering is the goal of the new study.

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**PHOTO PLATE 1: POINT PINOLE SITE**

**PHOTO PLATE 2: POINT MOLATE SITE.**

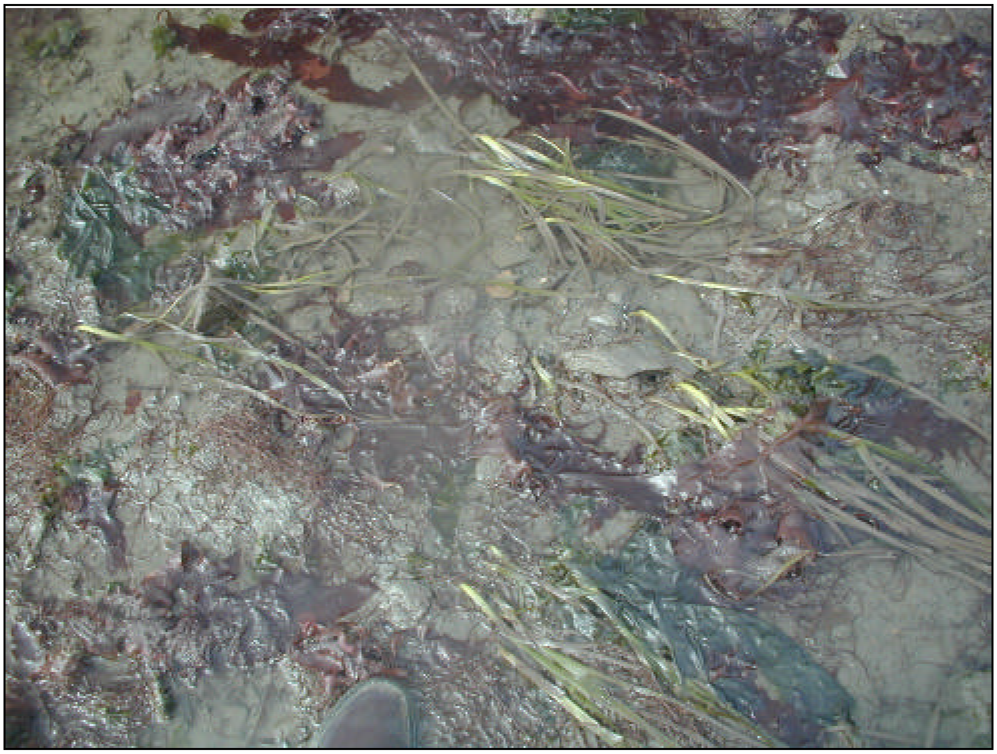

**PHOTO PLATE 3: KEIL COVE CONDITIONS - HEAVY MIX OF ALGAE AND EELGRASS.**

**PHOTO PLATE 4. KEIL COVE PERSPECTIVE FROM SHORE TO DEEP WATER. NOTE HEAVY ALGAL PRESENCE ATTACHED TO COBBLE.**

**PHOTO PLATE 5: CROWN BEACH IN AUGUST, SHOWING RESULTS OF HEAVY SEED SET AND ONSET OF EARLY FLOWERING.**